DATUM SHIFTS AND DIGITAL MAP COORDINATE DISPLAYS

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Paper maps may be printed with reference points for several different grid systems. Changing the datum of the map can cause these grid systems to shift by different distances. When digital maps–such as U.S. Geological Survey (USGS) digital raster graphics (DRG)–are used in geographic information systems (GIS), screen coordinate readouts may be very different from the values printed on the original paper map and may not match users' estimates of what the shifted values should be.

Since the mid-1980's, USGS topographic maps have shown the shift between the 1927 North American Datum (NAD 27) and the 1983 North American Datum (NAD 83) as dashed crosses near the corners of the map. All USGS quadrangle revisions are now done on NAD 83. Changing the datum of a quadrangle moves the neatline relative to the ground, which means that adjacent quadrangles on different datums will not join exactly.

Quadrangle neatlines are defined by latitude and longitude lines. The network of these lines is called the graticule. Plane coordinate systems are also shown on USGS maps, and these also shift when datums are changed. But changing the datum may cause different grid systems to shift by different distances.

The Real World, Maps, and Coordinate Systems

Maps are abstract representations of the world. USGS topographic quadrangles show selected surface features, such as roads, water bodies, and buildings, as well as the positions of small fixed objects, such as survey markers.

Many different coordinate systems are used to describe the positions of these features. Some coordinate systems are spherical, some are ellipsoidal, and some are planar. But in all cases, the coordinate systems are mathematical abstractions. Coordinate grids and numbers may be printed on a map along with roads and buildings, but these grids are not real-world features and should not be thought of as being "fixed" in the same sense as roads and buildings are.

There are infinitely many cartographic coordinate systems; USGS topographic quadrangles often show reference points for as many as four. The relationships of these systems to each other and to the ground can be quite complex.
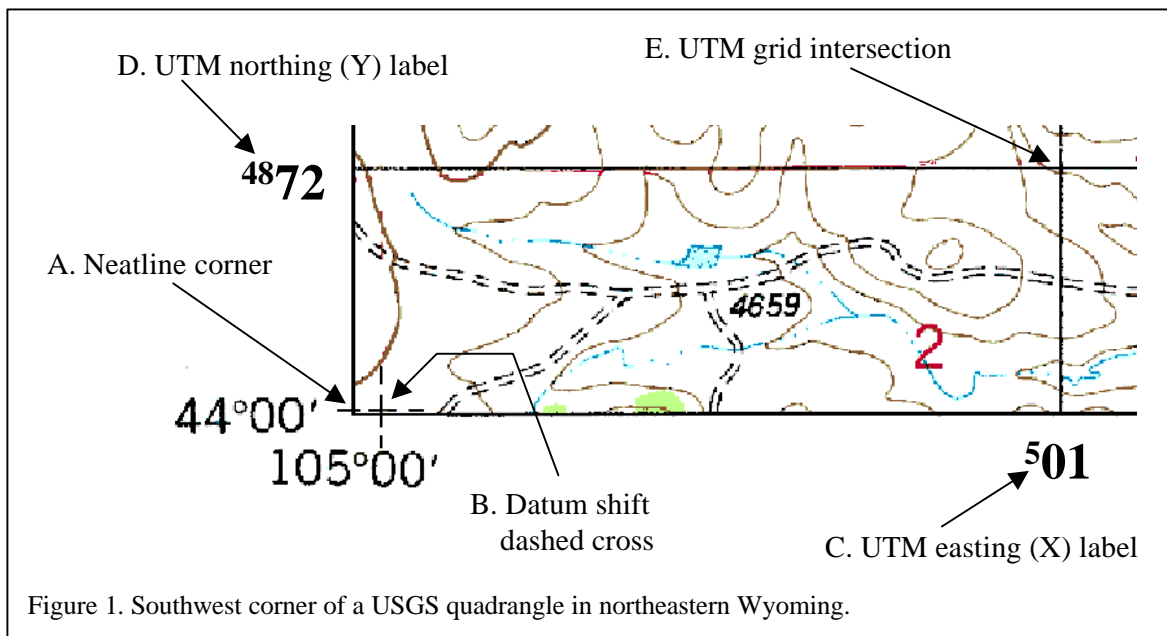

Figure 1. Southwest corner of a USGS quadrangle in northeastern Wyoming.

Table 1. Graticule shift of the map in figure 1.

| | | NAD 27 | | NAD 83 | |
| | | *a* | *b* | *c* | *d* |
Fig. 1		Longitude	Latitude	Longitude	Latitude
1	A	105° 00' 00"	44° 00' 00"	105° 00' 01.91245"	43° 59' 59.92221"
2	B	104° 59' 58.08761"	44° 00' 00.07778"	105° 00' 00"	44° 00' 00"
3	E	104° 59' 15.09669"	44° 00' 11.12662"	104° 59' 17.00750"	44° 00' 11.04918"

The NAD 83 graticule is shifted 42.6 meters east and 2.4 meters north of the NAD 27 graticule in the area of point A. Only the values in cells 1a, 1b, 2c, and 2d can be read or inferred directly from the map. All the other values are computed with software as described in the text.

Graticules and Datums

Consider a point such as the southwest corner of the USGS quadrangle illustrated in figure 1. The NAD 27 geographic values for this point, N44° W105°, are shown in table 1, cells 1a and 1b. Suppose the corner happens to fall exactly on some physical feature – say, a survey marker. Designating the point to be N44° W105° on NAD 27 is one of innumerable ways to describe this marker's location.

Another way is with latitude and longitude on the NAD 83 datum. The two datums use similar math models, but with different parameters. Equations exist that transform coordinates from one datum to the other, and these equations are coded in computer programs such as NADCON, written by the National Geodetic Survey (NGS). Converting the NAD 27 geographic values to NAD 83 values gives the coordinates shown in table 1, cells 1c and 1d.
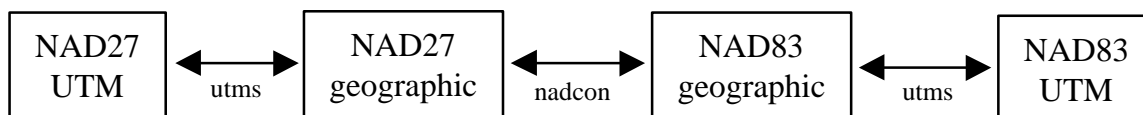

Figure 2. Conceptual view of computation steps for NAD 27-NAD 83 coordinate conversions. The arrows are labeled with the names of National Geodetic Survey freeware.

This conversion labels the survey marker with different numbers, though the physical marker has not moved. But the quadrangle corner **has** moved, because quadrangle neatlines are mathematical abstractions, not real features. The NAD 83 quadrangle neatline corner (N44° W105°) is 42.6 meters east and 2.4 meters north of the survey marker. This offset is shown with a dashed cross on the USGS quadrangle.

Table 2. Universal Transverse Mercator grid shift of the map in figure 1.

| | | NAD 27 | | NAD83 | |
| | | *a* | *b* | *c* | *d* |
Fig 1		Easting (X)	Northing (Y)	Easting (X)	Northing (Y)
1	C	501,000 m		500,957 m	
2	D		4,872,000 m		4,872,213 m
3	E	501,000 m	4,872,000 m	500,957 m	4,872,213 m

In the NAD 27-NAD 83 conversion, the UTM X grid line with value 501,000 moved 43 meters east and the UTM Y grid line with value 4,872,000 moved 213 meters south.

Plane Grids

The Universal Transverse Mercator (UTM) grid values in the area of the quadrangle corner do not shift by the same ground distance. The relationship between NAD 27 UTM and NAD 83 UTM is so complex that it is reasonable to say there is no direct relationship. Coordinate values are normally converted between these systems in the three-step process illustrated in figure 2.

The map in figure 1 has UTM grid labels printed close to the southwest corner (points C and D). The NAD 27 UTM values for the grid intersection at point E are given in cells 3a and 3b of table 2.

The NAD 27 UTM values can be converted to NAD 27 geographic values with another NGS program called UTMS. The geographic values are then converted between datums with NADCON, and the new geographic values converted to NAD 83 UTM values with UTMS. The final results of these calculations are shown in cells 3c and 3d, table 2. The intermediate latitude and longitude values for point E are shown in table 1.

The datum change shifted the UTM grid 43 meters east and 213 meters south, a much greater distance than the graticule shift. Changing the shape of the reference ellipsoid causes changes in Y values to accumulate with distance from the origin. Since the UTM grid system has its Y origin at the equator, a large difference accumulates between latitude 0º and latitude 44º.

Common User Problems Related to Datum Shifts

The differences between the graticule shift and the plane grid shift can be especially confusing in GIS environments:

- Imagine a USGS map published on NAD 27. The DRG for this map is also cast on NAD 27. It is not difficult to load this DRG into a GIS and recast it to NAD 83. The GIS coordinate readout will then show that the dashed datum shift crosses have "even" values characteristic of neatline corners (for example, N44° W105°), while the solid neatline corners will have "shifted" values. This is what most people would expect.

  However, when the screen cursor is moved to one of the UTM tick marks on the quadrangle neatline, the UTM coordinate readout is **not** what many people expect. The difference between the GIS readout and the label printed on the map may be several hundred meters, many times the ground distance of the graticule shift shown by the dashed crosses.

- Confusion deepens when the user and the GIS have different ideas about what coordinate system is being used. Suppose that a user joins a number of quadrangle datasets, most of which are cast on NAD 27, but one of which is on NAD 83. Some software may recast the odd dataset to match the others. In other cases, the user may move the NAD 83 data to make the neatlines join without being fully aware of this procedure's effect on coordinate values. In either case, the coordinate values printed on the map will not change to reflect the digital manipulation.

- Strictly speaking, there is no obligation for different grid systems on the same map to be cast on the same datum. It is not a cartographic error to print a map with an NAD 83 graticule and an NAD 27 UTM grid, provided that adequate explanations are given in the legend or metadata. Some USGS quadrangles in Hawaii and other Pacific islands actually have neatlines and plane grids referenced to different datums. (The reasons for this are complicated, having to do with the islands' geodetic isolation before global positioning system technology.) Although the maps are correctly compiled, the coordinate labels appear to be inconsistent when digital versions of the maps are viewed in a GIS.

Additional Information

The NGS programs NADCON and UTMS are available for free downloading at
- http://www.ngs.noaa.gov/PC_PROD/pc_prod.shtml

Some Web pages with useful information about datums:
- http://www.utexas.edu/depts/grg/gcraft/notes/datum/datum.html
- http://164.214.2.59/GandG/geolay/TR80003A.HTM
- http://users.netonecom.net/~rburtch/geodesy/datums.html

A good nonmathematical explanation of geodesy:
- *Introduction to Geodesy*, James R. Smith, John Wiley and Sons, 1997.

A paper with more detail about the relationship between map graticules and plane coordinate systems:
- http://mcmcweb.er.usgs.gov/drg/mercproj/index.html